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DTU Mechanical Engineering
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Waste Heat Recovery for Offshore Application

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1 Motivation

With increasing incentives for reducing CO_2 emissions, energy optimization on offshore platforms becomes a focus area. Gas turbines efficiency in offshore application typically ranges from 20-30%. To enhance their performance a bottoming cycle is introduced. A preferable technology is the organic Rankine cycle (ORC) because of its low gas turbine outlet temperature, space and weight restrictions. The case of study is the Draugen platform in the Norwegian Sea.

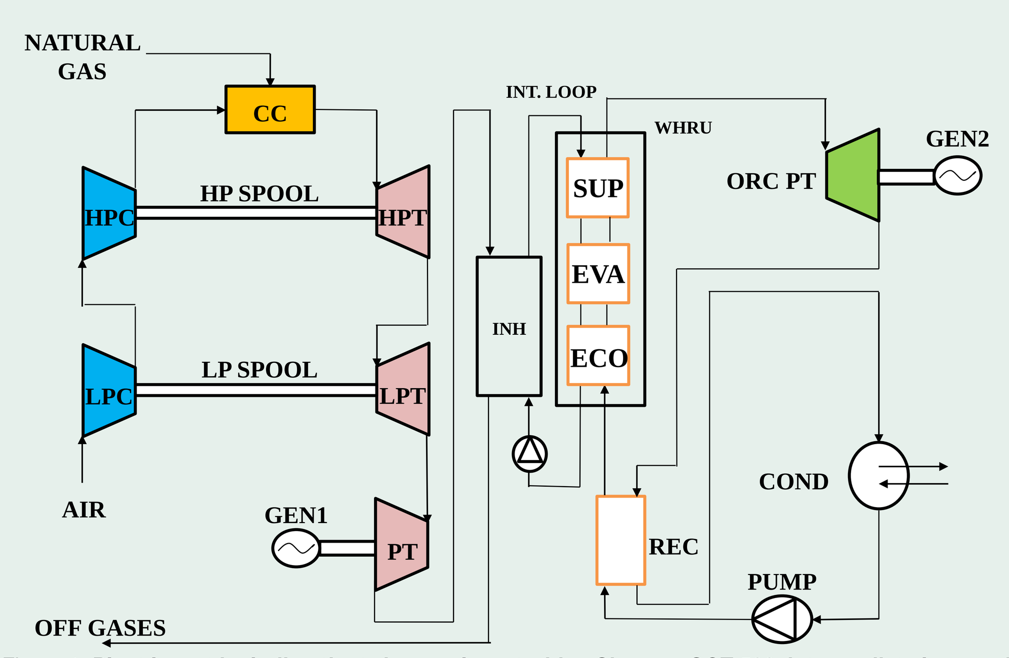

Figure 1: **Plant layout including the twin-spool gas turbine Siemens SGT-500, intermediate loop and the Organic Rankine Cycle**

Figure 2: **Draugen offshore oil platform, North Sea, Kristiansund, Norway**

2 Methods

DNA (Dynamic Network Analysis) is the simulation tool used for the system analysis. The fluid library has been extended by linking DNA with the commercial software REFPROP 9; more than a hundred real media including hydrocarbon fluids are now available.

3 Plant Analysis

The plant is constituted by the Siemens SGT-500 twin spool gas turbine, the intermediate loop and the ORC. The low and high pressure axial compressors are mechanically coupled by two distinct shafts with the low and high pressure turbines while the power turbine drives the generator. The fuel is assumed to be natural gas.

Figure 3: **Twin-spool gas turbine Siemens SGT-500**

Table 1: **Design point specifications for the Siemens SGT-500 twin-spool gas turbine on the Draugen platform [1]**

Gas Turbine data [1]		
Turbine inlet temperature	850	[°C]
Exhaust off gases temperature	376	[°C]
Exhaust mass flow	93.5	[kg/s]
Net power output	17.014	[MW]
Heat rate	11312	[kJ/kWh]
Fuels	Naphtha, crude oil, heavy fuel oil, bio oil, natural gas, syngas	

DOWTHERM Q is utilized as heat carrier: it presents low viscosity, better thermal stability and heat transfer coefficient with respect to hot oils through its operating range [2]. The off-gases temperature requires fluids with a high critic temperature. Toluene, cyclohexane, cyclopentane and benzene are therefore selected as ORC working media.

Table 2: **Thermodynamic state at critical point and hazard rating for the four ORC working fluids under investigation. Hazard classification is based on HMIS (Hazardous Materials Identification System) developed by the American Coatings Association**

Fluid	T_c [K]	p_c [bar]	ρ [kg/m^3]	Health Hazard	Fire Hazard	Physical Hazard
Benzene	562.02	49.06	304.8	2	3	0
Cyclopentane	511.69	45.15	267.9	2	3	1
Cyclohexane	553.64	40.75	273	1	3	0
Toluene	591.75	41.26	292	2	3	0

4 Results & Discussions

Increasing ORC maximum pressure enhances the efficiency of the bottoming cycle. The area between DOWTHERM Q and the organic fluid is lowest for cyclohexane meaning that a higher performance is achieved. Moreover cyclohexane presents the lowest health hazard according to the HMIS. Previous works considered 20 bar as maximum pressure for the working fluid [3]. However, when maximum pressure is increased area requirements for the waste heat recovery unit are higher. In this sense toluene represents a valid alternative.

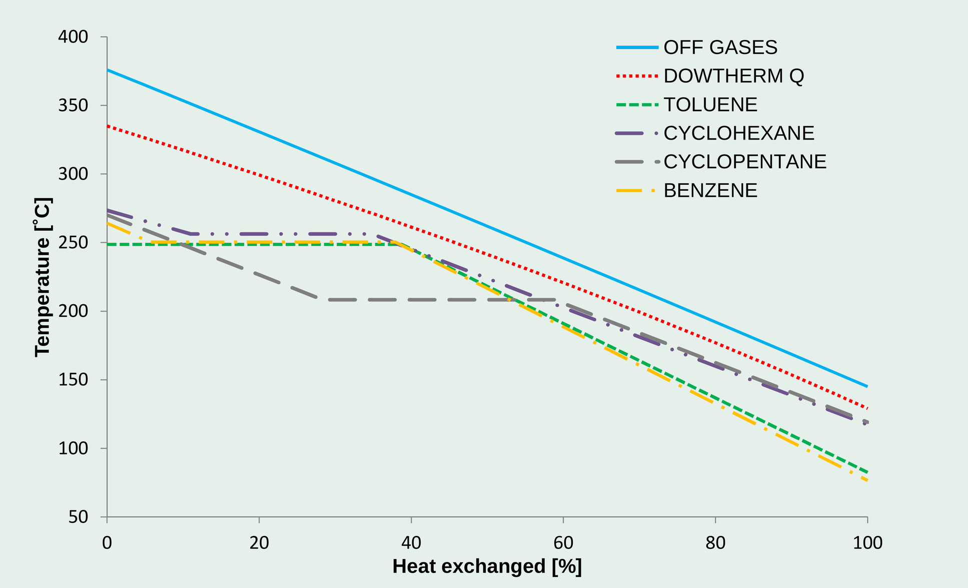

Figure 4: **Temperature vs. heat exchanged inside the waste heat recovery unit (Maximum pressure of toluene is set to 16.4 bar and to 30 bar for the other working fluids)**

Figure 4 shows that SGT-500 efficiency (31.4%) increases to 43.7% and 44.3% for case A (toluene) and B (cyclohexane). Net power output rises to 23.9 MW, meaning that, with a modified schedule for the three gas turbines, fuel consumption and emissions can be decreased.

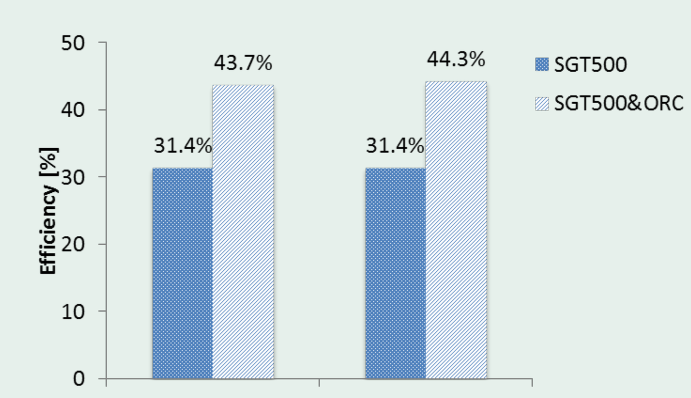

Figure 5: **SGT500 and overall thermal efficiency for toluene case A) and cyclohexane case b) as ORC working fluid.**

5 Acknowledgements & References

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[1] SIEMENS Industrial Turbomachinery. GT35 Performance & Technical Information, 2010.

[2] Dow Chemical. Dowtherm Q Heat Transfer Fluid, 1997.

[3] Lai N A Wendland M Fischer J. Working fluids for high-temperature organic Rankine cycles. *Energy*, 36(1):199–211, January 2011.

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